DRY SEPARATION OF PLASTICS BY DENSITY USING FLUIDIZED BED TECHNOLOGY

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The project was performed in two stages: separation of scrap plastics in a rotating screen fluidized bed (January 1 - June 30th), and construction and preliminary testing of the inclined channel bed (July 1 - August 31).

ROTATING SCREEN STUDIES

ABSTRACT

This report concerns a study on the continuous separation of particles of simulated shredded waste plastics in a rotating-screen fluidized bed (RSFB). Systems with small density differences were used, both because of their practical significance and to test the limitations of the rotating-screen fluidized bed as a particle separation device. Some degree of separation was observed even with specific gravity differences as small as 0.05, and particle size within the range 1.0 to 5.0 mm was found to be a relatively unimportant variable. With each system studied, an optimum stirrer rotation rate was found, and separation effectiveness deteriorated as the feed rate was increased.

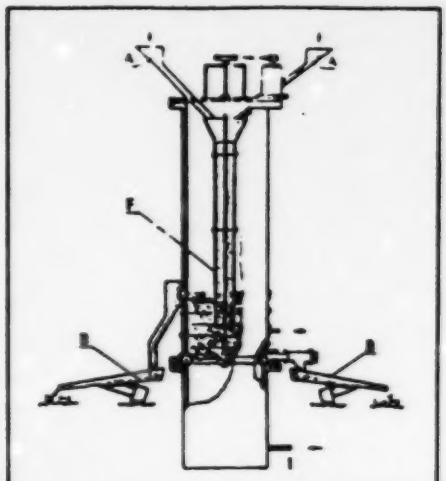
Society faces an increasingly troublesome solid wastes disposal problem, and it is becoming apparent that recovery, separation and recycling of household and industrial solid wastes will in the future become more important. Plastics constitute an important component of solid wastes in the industrialized societies (generally 5-7% by weight), and there is a need for efficient, economical methods for their separation. The only currently available method which meets these criteria is float-sink in water, which effectively only permits separation of the polyolefins from denser components. The rotating-screen fluidized bed has previously been shown to be selective when using particles of uniform size and shape (1), and it has the advantage that the separation density is easily controlled, with values below as well as above unity being feasible. It is derived from the mechanically fluidized bed (2, 3), which has been shown to be superior to an ordinary fluidized bed as a particle separator in systems composed of relatively large particles in a fluidizing medium.

EQUIPMENT, MATERIALS AND PROCEDURES

The RSFB (fig.1) consisted of a cylindrical fluidized bed equipped with an axial rotatable shaft connected to a motor. The shaft has attached to it at regular intervals, within the fluidized bed, a set of horizontal, circular disks made from coarse wire mesh (12.5 mm apertures in this case). Between the disks, attached to the shell of the fluidized bed, and positioned horizontally in radial directions, there are a number (eight in this study) of fixed rods. For continuous separation, the bed has a materials supply system which delivers feed to the centre of the bed, and also outlets for

product streams both at the surface and just above the distributor grid. Additional details may be found in (1).

Rotation of the screens within the fluidized bed, in combination with the fixed rod obstructions, renders the bed fluid while at the same time inhibiting the formation of bubbles. Under these conditions gravity-induced relative motion is possible between particles, while at the same time vertical transport by the bubble wake mechanism is avoided. These circumstances are favourable for the separation of particles by the "float-sink" technique.



A: Feed inlets; F: feeding funnel; B: outlets; I: air inlet

Figure 1

In this study the RSFB was used for separation of particles of various simulated shredded waste plastics, which will be referred to as primary particles, in a bed of fluidizing medium. In any given materials system one component of the primary particles tends to report primarily to the floats outlet, and is referred to as the flotsam component. The other component, which reports primarily to the sinks outlet, is termed the jetsam component.

The primary particles were obtained by shredding virgin plastic sheet or plastic bottles, their size being in the range 1.0 to 5.65 mm (Table 1), whereas the particles of fluidizing medium had a size-range of 0.2 to 0.6 mm. (Table 2). (In one system the primary particles had the shape of cubes). Medium and primary particles in the products were separated from each other by screening, the medium being returned to the bed with fresh primary stock. The separation density is approximately equal to the bulk density of the fluidized bed, and is determined primarily by the density of the particles of medium. The medium can contain two or more components, since relatively little separation of its constituents occurs in the RSFB. Separation density was adjusted by controlling the composition of the medium.

The feed rate and the rate of withdrawal of the sinks products stream were controlled by vibratory solids feeders, the overflow constituting the floats product stream.

The composition of the various streams was determined by selecting a relatively small sample using a sample splitter, followed by visual separation (the various components were colour-coded) and weighing.

The bed operating conditions contain six degrees of freedom: the

feed rate (1); fraction by weight of medium (2); ratio of flotsam to jetsam in the feed (3); ratio of rate of withdrawal of bottom product to feed rate (4); stirring rate (5); and fluidizing air velocity (6). In any series of runs designed to illustrate the effect of any one variable, five other degrees of freedom were maintained constant.

TABLE 1
PHYSICAL PROPERTIES OF THE PRIMARY PARTICLES

Composition	Mean size (mm)	Shape	Mean density (kg/m^3)
Polypropylene	3.3(1)	Irregular	0.884
Polyethylene	3.3(1)	Irregular	0.927
Polystyrene	3.3(1)	Irregular	1.029
PET	5.4(2)	Flakes	1.305
PET	2.2	Cubes	1.38
PVC	3.4(2)	Flakes	1.394
PVC	2.9	Cubes	1.44

(1) Mid-point of sieving size range 1.0 - 5.65 mm

(2) Diameter of mean equivalent disk, based on flake thickness (0.41 mm for PET and 1.0 mm for PVC), mean weight per particle and mean density.

TABLE 2
PROPERTIES OF THE FLUIDIZING MEDIA

Composition	U_{mf} (mm/s)	Bulk density (kg/m^3)
17% salt, 83% sugar	108	889
40% sand, 60% salt	72	1302

Densities were measured using float/sink in solutions of varying densities, and the shredded particles appeared to have a range of

values. The standard deviations in the observed densities were in the range of 10 to 25 kg/m^3. These variations may be due to the presence of microscopic bubbles of air embedded in the particles.

The PET and PVC flakes were obtained by shredding virgin sheet, and were flat in one dimension but irregular in the other dimensions. The cubes of PET and PVC were very regular. The fact that their density was larger than that of the corresponding flakes is not inconsistent, because these materials may vary in density due to the method of manufacture, the degree of polymerisation, the nature and extent of added plasticisers, and occluded bubbles of air.

The other shredded particles (PP, PE and PS) were obtained by shredding bottles and tubs with relatively thick walls, so that they had an irregular shape in three dimensions.

RESULTS

Separations were studied with the following materials systems: polypropylene/polystyrene in sugar/salt medium; polyethylene terephthalate (PET)/polyvinyl chloride (PVC) flakes; PET/PVC cubes; (the latter two systems in a salt/sand medium); polypropylene/ polyethylene in a sugar/salt medium. These materials were selected not only because of their potential significance in recycling applications, but also to obtain information on aspects of the behaviour of the RSFB which had not been addressed in previous studies (1, 2). These included systems with very small specific gravity differences between components, and the effect of particle shape. Bed height and bed diameter equalled 550 mm and 305 mm, respectively, in these experiments.

Separation results are presented in terms of two separation indices, P_f and P_j, defined as follows:

$$P_f = \frac{\dot{M}_{fs}\,\dot{M}_{mt}}{\dot{M}_{ft}\,\dot{M}_{ms}} \qquad (1)$$

$$P_j = \frac{\dot{M}_{jr}\,\dot{M}_{mt}}{\dot{M}_{jt}\,\dot{M}_{mr}} \qquad (2)$$

M is a mass flowrate. Subscripts f and j refer to flotsam and jetsam, respectively, whereas subscripts s and r refer to the sink (lower) and the rise (upper) outlets, respectively. Subscript t indicates total rate of mass flow of a given component into or out of the bed. P_f has the following significance: if all the flotsam

is correctly placed and goes to the upper outlet, P_f equals zero. On the other hand, if the amount of flotsam appearing at each outlet is proportional to the rate of withdrawal of medium at that outlet, no segregation is deemed to have occurred, and P_f equals 1.0. The meaning of P_j is analogous. A value of P_f greater than unity indicates that a component designated as flotsam is behaving as jetsam; similarly a value of P_j larger than unity means that the jetsam component is acting as flotsam.

Figure 2 shows plots of P_f and P_j versus screen stirring rate, with shredded PP/PS particles. Other parameters were maintained constant: U/U_{mfo} = 1.15 (U_{mfo} = fluidization velocity of the medium); feed rate of plastics = 12.7 kg/h; ratio of flotsam to jetsam in the feed: 1.0; medium feed rate = 61 kg/h; ratio of withdrawal rate at bottom outlet to withdrawal rate at upper outlet = 0.575. Minima in the two functions are observed, but not at the same rotation rate. The optimum rotation rate for separation is in the region 20 to 40 r.p.m. At 20 r.p.m. each product contains between 6% and 7% of contamination, on a medium-free basis, defined as flotsam in the bottom product or jetsam in the top product.

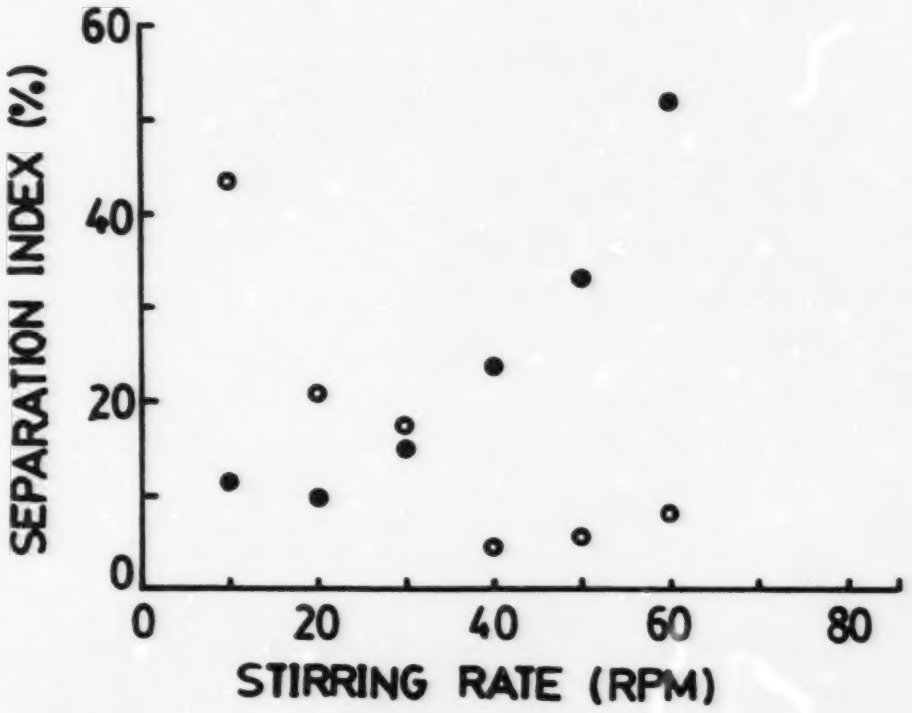


Figure 2 Separation index vs rotation rate (PP/PS).
○ flotsam; ● jetsam.

Figure 3 gives P_f and P_j plotted as functions of U/U_{mfo}, at similar conditions to the previous plot but with a constant stirring rate of 20 r.p.m. A shallow minimum is observed in the plot of P_j, whereas the plot of P_f does not appear to have a discernable trend.

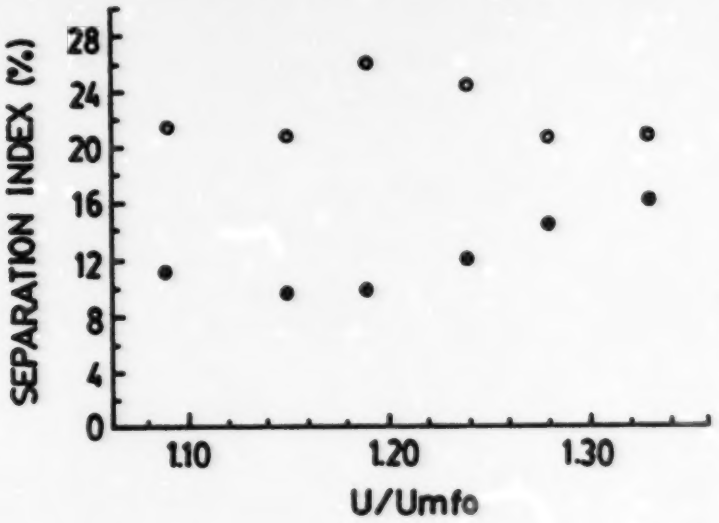


Figure 3. Separation index vs U/U_{mfo} (PP/PS).
o flotsam; ● jetsam.

Results with the systems PET/PVC (shredded particles), PET/PVC (cubical particles) and PP/PE were similar, but due to the smaller differences in density of the primary particles separations with these systems were inferior to those obtained with the system PP/PS. P_f and P_j are shown plotted versus feed rate of plastics in figs.4 & 5, respectively, for the four systems studied.

The difference in the mean specific gravities of the PP and PS particles equals 0.145, whereas the specific gravity differences between the other systems were significantly smaller: 0.089 for PET/PVC shredded flakes, 0.060 for PET/PVC cubes and 0.063 for shredded PP/PE.

An interesting conclusion that can be drawn from figs 4 & 5 is that particle shape seems to have very little effect on the behaviour of particles in a RSFB. This result is particularly surprising with the PET flakes, which had a thickness (0.41 mm) comparable with the mean size of the particles of fluidizing medium.

Figure 6 shows values of P_j well in excess of 100% at high values of rotation rate, with shredded PET/PVC, indicating that under these conditions the jetsam preferentially exited from the floats outlet. The reason for this anomalous behaviour is unclear, especially since bed bulk density decreased at high rotation rates.

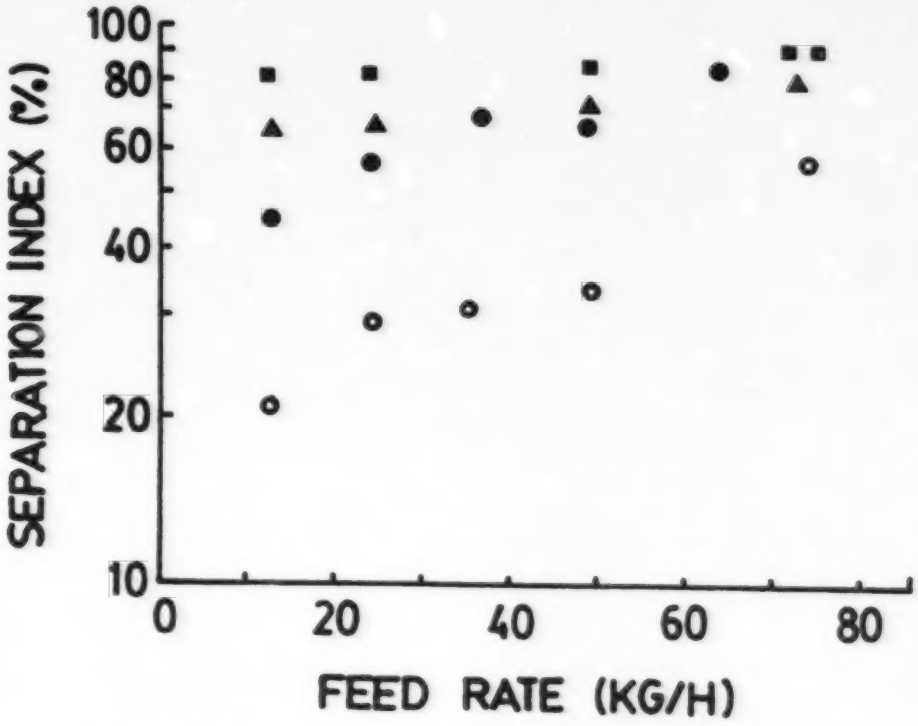


Figure 4. Flotsam separation index vs plastics feed rate.
○ PP (with PS) ● PET (shredded, with shredded PVC);
PET (cubes, with PVC cubes); ▪ PP (with PE)

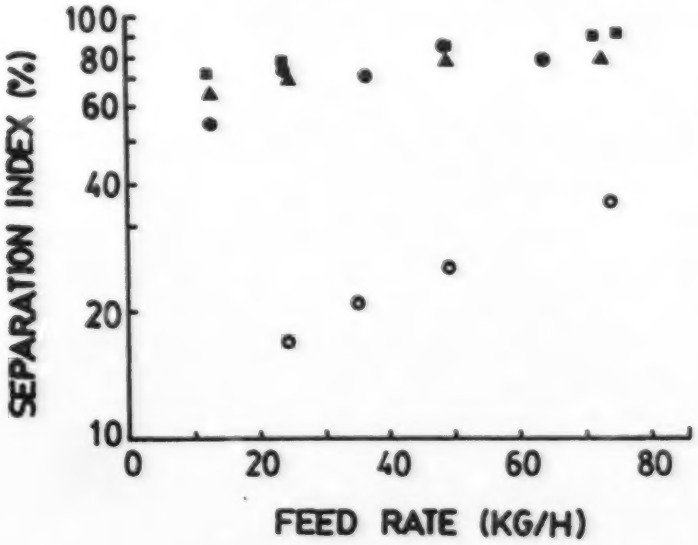


Figure 5. Jetsam separation index vs plastics feed rate.
○ PP (with PS) ● PET (shredded, with shredded PVC);
PET (cubes, with PVC cubes); ▪ PP (with PE).

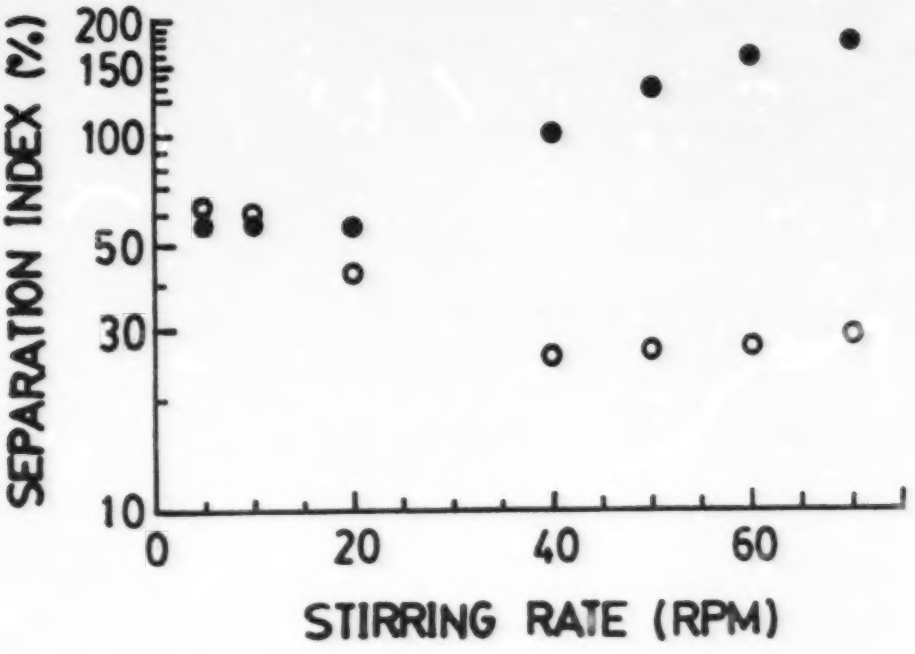


Figure 6. Separation index vs rotation rate, shredded PET/PVC. ○ flotsam; ● jetsam.

A sieving analysis on the flotsam and jetsam components in the product streams demonstrated a small effect of particle size on separation (Table 3).

TABLE 3
MEAN SIZES OF FLOTSAM & JETSAM IN PRODUCTS

Component	Mean particle size (mm)
Jetsam in floats	2.37
Jetsam in sinks	3.02
Flotsam in floats	3.02
Flotsam in sinks	3.67

RECYCLING EXPERIMENTS

Experiments were carried out to determine the level of improvement achievable in the separations, by recycling the products to the RSFB. Using the system PP/PS and a feed rate of 36 kg/h, products containing 8.2% PP in the sinks and 78.1% PP in the floats were obtained. On further processing of the first-stage floats product at 13 kg/h, the second-stage floats product contained 93.5% PP and the bottoms product 56% PP. Reprocessing the first-stage bottoms product at 12 kg/h yielded a second-stage bottoms product containing 0.8% PP and a floats product containing 56% PP. Since at each stage the sinks and floats streams were approximately equal in volume, only approximately one half the feed volume was contained in the purified products. In any application the balance would be reprocessed with fresh feed.

CONCLUSIONS

The principal conclusions drawn from the study were:

(1) Under favourable conditions a significant amount of separation of flotsam and jetsam was observed even with differences in specific gravity as low as 0.060.

(2) Particle size and shape play a relatively minor role in the separation process.

(3) There is an optimum rotation rate at which each component's separation index has a minimum value.

(4) Providing it was above the minimum fluidization velocity of the fluidizing medium, the fluidizing air velocity had only a weak effect on the separation index values.

(5) Separation effectiveness invariably declined as feed rate increased.

THE INCLINED CHANNEL SEPARATOR

In the rotating-screen fluidized bed the contents are mixed by the combined effects of the rotating screens and the static bars. A similar environment can be created by letting the material, consisting of the particles of mixed plastics to be separated together with fluidizing medium, flow downhill over static obstacles, such as coarse mesh screens or numerous horizontal rods, and collecting products from the upper and lower strata at the bottom end of the inclined channel. This device (Fig.7) contains no internal mechanical devices and is simpler and cheaper than the rotating-screen fluidized bed.

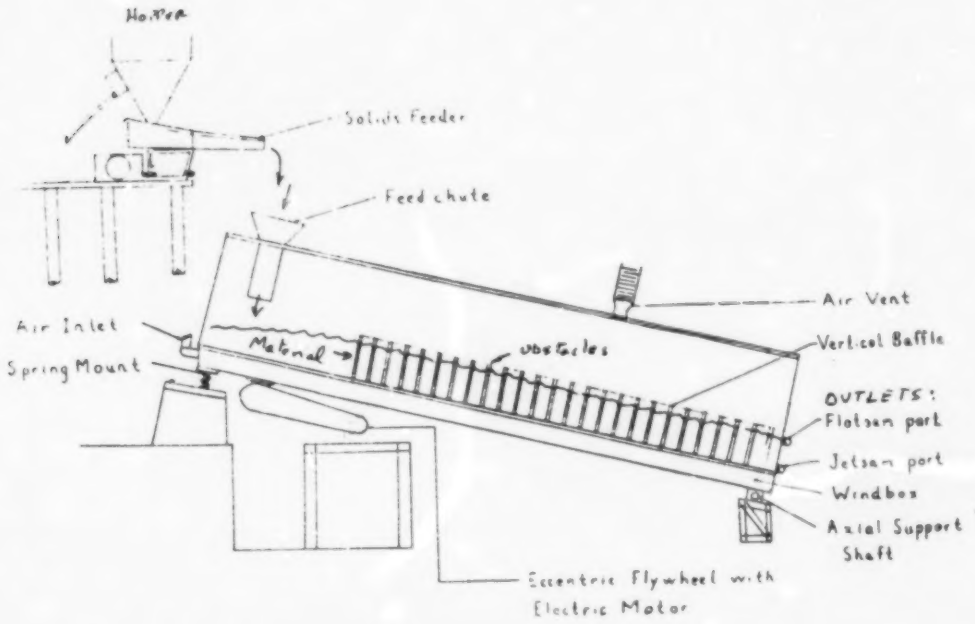


Figure 7. Schematic of the inclined channel separator

A 4-metre long inclined channel separator was constructed during the second phase of the project. The "obstacles" consisted of one-half inch "chicken wire" mesh folded accordion style so that the material is forced to repeatedly pass over the mesh.

Preliminary tests indicated several problems with the first version of the equipment:

(1) The particles of plastics tended to deposit on the bottom ("defluidize") and become immobile. Eventually the entire channel would become blocked and unusable.

(2) Particles of plastics tended to block the half-inch screens.

(3) Material flowed only over the upper surface of the bed instead of uniformly throughout the cross-section.

We are attempting to overcome these difficulties by means of the following modifications:

(1) The upper end of the channel was mounted on springs and an off-centre flywheel was attached to the air channel. The entire bed is thereby vibrated when the flywheel is rotated, which should cause defluidized material to migrate downhill.

(2) The screen is currently being replaced by numerous transverse, horizontal 4 mm brass rods, which should eliminate the blockage problem.

(3) Barriers will be placed across the upper surface to prevent it

from moving downhill. This measure was tried when the screen was still in place and appeared to work well.

Despite the aforementioned difficulties a run was more or less successfully completed with the original inclined channel with surface barriers in place. The plastics consisted of polyethylene and acrylic pellets. The composition of the products was: upper stream contained 73% polyethylene, and lower stream contained 38% polyethylene (on a medium-free basis). We feel this is an encouraging beginning because of the operational difficulties encountered.

PLANS FOR CONTINUATION

Although funding from the ministry has terminated, the project will continue under NSERC auspices. As soon as the modifications have been completed the separation runs will be resumed, using simulated plastic scrap. The ministry will be kept informed concerning progress on this project.

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